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title

Development of a generic didactic model for simulator training

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Het doel van het onderzoeksplan dat in dit rapport wordt beschreven is gericht op het ontwikkelen van een generiek didactisch model voor het trainen van tijd-kritische voertuigbesturingstaken op een simulator. Omdat deze taken zowel perceptief-motorische als cognitieve taak-componenten hebben die in een dynamische omgeving geïntegreerd moeten worden tot de complete taak wordt wel verondersteld dat er speciale time-sharing vaardigheden ontwikkeld moeten worden om goed op zo'n taak te kunnen presteren. De rol van de instructeur is daarbij van groot belang. Hoe deze het leerproces beïnvloedt is nog niet geheel duidelijk omdat diens interventies in het leerproces niet goed in een isolement gezien kunnen worden. Afhankelijk van de context kunnen interventies verschillende effecten hebben. Om hierover meer duidelijkheid te krijgen zal het empirische gedeelte van dit project gericht zijn op tutoring. Met tutoring wordt gedoeld op de ondersteuning die de instructeur geeft tijdens het uitvoeren van trainingsactiviteiten. Tutoring is het meest dynamische en interactieve aspect van instructie en waarschijnlijk het meest relevant voor dit onderzoek.

Het tutoring-proces kan beschreven worden in termen van interventies die weergegeven kunnen worden in termen van conditie-actie regels. Een voldoende complete verzameling van dit soort regels kan dienen als een model voor tutoring.

Vanwege de toegankelijkheid van het domein wordt autorijden als beste geschikt geacht voor het doen van verder onderzoek. Bovendien zijn experimenteer faciliteiten zoals een rijsimulator aanwezig op TNO-TM.

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A didactic model specifies the relation between learning, and training and instruction factors. The development of such a model is motivated by the need to control training and instruction factors in research on simulator fidelity, the need to assess the benefit of training simulators, e.g., relative to other training media, and the need for developing more efficient instructional systems to support simulator-based training and instruction. For several reasons, it is proposed to focus the empirical work on tutoring aspects associated with car driving skills.

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M.L. van Emmerik, W.R. van Joolingen en J.C.G.M. van Rooij

SAMENVATTING

Op het gebied van simulatortechnologie wordt veel vooruitgang geboekt. Hierdoor worden simulatoren steeds vaker gebruikt als leermiddel. Desondanks is er nog weinig onderzoek gedaan naar de didactische aspecten van simulatortraining. Inzicht in hoe de didactische factoren de effectiviteit van de simulator bepalen is onontbeerlijk voor het effectief en efficiënt gebruik van trainingssimulatoren. De effectiviteit van simulatortraining kan worden uitgedrukt in termen van leren, transfer en retentiecriteria. Kennis met betrekking tot de gevolgen van trainings- en instructie-factoren op de effectiviteit van een simulator kan omschreven worden in een didactisch model. Zo'n model is een beschrijving van trainingsresultaten als een functie van trainings- en instructie-factoren. Een didactisch model kan gebruikt worden als uitgangspunt voor het specificeren van de voorwaarden voor het trainingsprogramma, voor instructieondersteuning en voor instructeurstraining.
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1 INTRODUCTION

With advances in simulation technology, simulators are increasingly used as a medium for training high-performance tasks. Insight into factors that determine the effectiveness of simulator-based training is indispensable in designing, procuring, and using training simulators effectively and efficiently. The effectiveness of simulator-based training can be expressed in terms of learning, transfer, and retention criteria. Knowledge with respect to the impact of training and instruction factors on simulator effectiveness can be described in terms of a didactic model. A didactic model is a systematic description of training results as a function of training and instruction factors. A didactic model may be used as the basis for specifying training program requirements, requirements for instructional support, and requirements for instructor training. Such a model may be more or less generic. The purpose of the research project described in this report is to develop a generic didactic model for simulator-based training of high-performance vehicle control tasks.

Chapter 1 presents a description of the domains in which training simulators are used. The approach to training that is typically adopted is described. After an introduction of basic terminology, the chapter ends with a discussion of the reasons for using simulators. The importance of research on training program aspects is stressed.

Chapter 2 opens with a definition of terms and introduction of a conceptual framework that is used to organize the issues with respect to simulator-based training and instruction. This chapter concludes with a specification of the research issues that will be addressed in this project and a preliminary inventory of some of the alternative approaches that may be used to address these issues.

Chapter 3 elaborates on tutoring as an area of interest for training high performance tasks, and suggests an outline for the step by step development of a model.

Given the research issues that have been specified in Chapter 2, in Chapter 4 the issue of which domain(s) should be the (primary) focus of this research project is addressed. Apart from substantive reasons this decision is also determined by secondary factors like available contacts, facilities, and funding opportunities.

2 HIGH-PERFORMANCE TASKS AND TRAINING SIMULATORS

High-performance tasks are defined as complex, time-critical tasks where the operator is in the primary control loop of the system (cf. Schneider, 1985). Most vehicle control tasks comply with this definition. An example is piloting a combat helicopter. The time-critical aspect derives from the fact that the to-be-controlled system is dynamic and operates in a dynamic and often dangerous or hostile environment. The complexity of these tasks resides in

the number of, and interactions between multiple requisite skills which, apart from perceptual-motor skills, typically also require time-sharing with (subsidiary) procedural and cognitive skills.

One of the training characteristics of these skills is that many people fail to develop proficiency so that selection is often required. Even after selection, the training duration required to reach an operational level of performance may be considerable. Typically there are large differences between novice, advanced, and expert operators, not only with respect to the speed and accuracy of performance, i.e., quantitatively, but also with respect to the use of different strategies, i.e., qualitatively.

Training of high performance tasks usually proceeds in interaction with a training scenario and under close supervision of an instructor. This approach to instruction is frequently referred to as "apprenticeship instruction" (Schank & Jona, 1991). Training scenarios usually are composed by the instructors on the basis of more or less typical real-life conditions and events and are presented from simple/elementary to more complex/demanding. Most instructors are experienced operators that are assigned to the duty of instruction and usually have little or no didactic background.

With advances in simulation technology, an increasing amount of training and instruction is delivered on training simulators instead of on the real system. The most important practical reasons for using training simulators are that many skills required during the execution of high-performance tasks cannot be trained on the real system, because:

1 it is too dangerous, for instance, training of emergency procedures;
2 the necessary conditions are not available, e.g., for training desert operations in The Netherlands;
3 or because there are insufficient opportunities to train on the real system, because:
   a it is too expensive, e.g., due to the expenditure of fuel or ammunition or due to the increased wear and tear that is incurred during training;
   b there is insufficient time available on the real system, e.g., due to maintenance duties and/or because of operational deployment;
   c the circumstances required for training do not occur frequently enough,
   d the possibilities for training are restricted by environmental regulations, e.g., noise, pollution, etcetera.
   e safety regulations preclude the execution of particular tasks or manoeuvres, for instance high speed car pursuit.

Unfortunately, there are limitations to what can be simulated. These limitations may reduce the perceived realism (face validity) of a training simulator and, hence, its acceptance as a training device by trainees and instructors. Also, apart from user acceptance, these limitations may reduce or impede the transfer of skills from the training simulator to the real system. In addition, the cost of training simulators may be very substantial. Procurement costs of training simulators may exceed the procurement costs of the real system (for a driving simulator this is almost certainly true, but in general the costs mainly depend on the functionality the simulator provides); the same applies to the costs of operating and maintaining training simulators. For this reason, much effort is being invested in investigating ways to optimize the benefit/cost

ratio of training simulators (Orlansky, 1989; Boldovici, 1987). However, it should be noted that empirical benefit/cost studies are relatively rare. Most of the studies that are reported in the literature focus on issues of fidelity, i.e., the extent to which the behaviour of the simulator mimics the behaviour of the operational system.

The comparison and assessment of the results of these studies is complicated by several factors, the lack of consistency in the definition of fidelity being the most prominent. In particular, older studies and studies in the field of engineering (e.g., Allen, Hays & Buffardi, 1986; Thomson, 1989) apparently fail to appreciate the fact that it is not the fidelity of the simulator that is the goal of simulation but the efficient transfer of training. Although these goals are certainly related, they are by no means the same (Lintern, Sheppard, Parker, Yates & Nolan, 1989). After reviewing the available literature, Korteling, Van den Bosch and Van Emmerik (1997) propose the following subdivision of the term fidelity: *physical fidelity* (simulator behaviour as specified by the mathematical model including face validity i.e.: the appearance of the simulator), and *psychological* or *functional fidelity* (pertaining to the similarity of trainee behaviour on the simulator and on the real system). In some cases then, it is clearly suboptimal to strive for high physical fidelity in simulation (Lintern et al., 1989; Patrick, 1992). The level of physical fidelity needed to achieve functional fidelity is related to the type of task to be trained, proficiency level, the difference between criterion performance and maximum performance (Boer, 1991), and, last but not least, didactic factors.

2.1 Didactic aspects of simulator training

Apart from the aforementioned practical reasons for using training simulators, there are also specific didactic reasons for using training simulators instead of the real system:

1 the possibility to control the type and timing of training events that are presented and, hence, the learning experiences that are offered to the trainee(s). This enables the provision of more learning experiences per unit of time and the planned distribution of learning experiences;
2 more possibilities to adapt the training task to the performance of the trainee(s);
3 more possibilities to provide "augmented" cuing and feedback, i.e., cues and feedback extrinsic to the (training) task;
4 more possibilities to register and diagnose trainee performance, e.g., for debriefing and/or administrative purposes;
5 more possibilities for automating the process of training and instruction and, consequently, for improving efficiency.

Compared to research on simulator fidelity, much less research effort is being invested in investigating the possibilities for exploiting the didactic possibilities that training simulators may offer. As noted earlier, the design and interpretation of simulator studies usually is construed in terms of the effect of different levels of fidelity on transfer. In most of these transfer studies an experimental group of subjects that is trained on a simulator is compared with a control group that is trained by conventional means (on the real system). Apparently, many transfer studies confound the effect of fidelity with the effect of training program: not

only is the experimental group trained on a different system but the way in which trainees are trained also differs qualitatively from the way trainees are conventionally trained. Because of this potential confounding between the effect of simulator fidelity and the effect of using different types of training, the results of these studies are difficult to interpret and only permit relatively crude assessments, e.g., "Are the results obtained with simulator-based training similar to conventional training?" or: "Does simulator-based training result in cost savings?". One might argue that knowledge about training and instruction factors that determine training effectiveness is a prerequisite for progress in research on the relation between simulator fidelity and transfer.

Another, and perhaps even more important, reason for being interested in the relation between training effectiveness and training and instruction factors is that, to a large extent, training and instruction factors determine training effectiveness and efficiency independent of the medium that is used for training. Given the same training simulator, training results may differ widely depending on the way in which the training program has been designed and delivered. In this respect, the way in which instructional support is implemented (Polzella, 1983) is an important determinant of training effectiveness and efficiency. Currently, the instructional support that is provided ranges from no support to instructor controlled monitoring and control facilities, (semi-)automated facilities are still relatively rare.

A major problem in designing effective training programs is that the knowledge base with respect to training and instruction is not well organized and suffers from a lack of theoretical cohesion (Van Rooij et al., 1995, 1997). Most of the guidelines that are encountered in the literature are formulated rather generally although they have been developed in the context of specific tasks. This renders it difficult to apply them. Another major problem is that most of the research focuses on individual performance and skill acquisition in the context of relatively simple, well-structured tasks. In particular, there is a paucity of research dealing with the integration of skills e.g., (part-task) training of time-sharing skills.

2.2 Didactic model

The purpose of this research project is to integrate current knowledge with respect to learning, training, and instruction into a didactic model that is specifically tailored to simulator-based training and instruction of high-performance tasks. A didactic model specifies the relation between 'learning', and 'training and instruction factors', i.e., factors that determine the results of the training process.

2.2.1 Learning

In this context, learning is defined as a relatively permanent change in behaviour due to training[1]. The learning process cannot be perceived directly but has to be inferred from

[1] Learning can be intentional or incidental. The latter type of learning is generally associated with experience, although this association is more one of emphasis than of principle. Many experiences are also driven by an intention to learn although this may not be the primary drive. The same applies with respect to the association

changes in behaviour during and after training (usually with respect to some baseline/ reference). The learning process can be viewed as an optimization process where the trainee (repeatedly) tries to perform according to a set criterion. Typically, for learning to be efficient (or at all effective) trainees need specific guidance. For instance, findings from research on discovery learning (Van Joolingen, 1993) show that trainees are often unable to systematically plan and monitor their own learning behaviour.

2.2.2 Training and instruction factors

Learning processes have been shown to be affected by a large number of training and instruction factors. Training factors are factors that are related to the sequencing, frequency, spacing, duration, and content of training activities. Instruction factors are factors that are related to the support provided before, during, and after the execution of training activities. This support can take a variety of forms and can be categorized in briefing, tutoring, and debriefing activities, respectively. These supportive activities can be regarded as catalysts for the training process.

For a specific training application, the choice of a particular set of training and instruction factors defines a training program, i.e., a controlled sequence of training activities supported by instruction. A training program can be viewed as a means to elicit/compress optimal learning experiences and as a means to control the degrees of freedom associated with learning.

2.2.3 Scope of the model

Ideally, a didactic model will be more or less *generic,* i.e., applicable to a particular set of tasks. Genericness can be reached in a number of different ways:

- A model can be generic because it is formulated in a rather abstract way (although this will limit its practical utility).
- Modelling a typical/representative task will also yield genericness because there is a large number of tasks that can be captured by the resulting model. (Since these tasks are not very specific, likewise, the model will be of limited use.)
- By making a model easily adaptable it can be called generic as well.
- More desirable, however, a model should comprise all relevant aspects, i.e., it should be generic because it is comprehensive. Depending on the number of factors that are considered and depending on the number and nature of the interactions between factors that are taken into account, a didactic model can be more or less comprehensive. As noted earlier, the focus of this project will be on factors that are relevant for simulator-based training of high-performance tasks. To identify these factors, factors that are encountered in the literature will be considered but current practices will also be taken into account. In order to be able to generalize findings obtained with one task to other tasks, a (skill-

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between intentional learning and training: many training activities result in the acquisition of particular knowledge and skills that do not belong to the intended focus of training but rather can be regarded as incidental by-products of the training process.

oriented) taxonomy of tasks is required. Such a taxonomy may provide the basis for a model that can specify the relation between, on the one hand, task characteristics, and, on the other hand, training and instruction factors. This model can be used to devise training for a variety of high-performance tasks. In a sense, a didactic model constitutes a theory of training. Due to the large number of potential factors and their interactions[2], the availability of such a theory is a prerequisite for setting priorities for research and for controlling the effects of non-experimental factors.

Although it is believed that, given available knowledge (Van Rooij et al., 1997), a (provisional) didactic model can be developed, the resources (e.g., in terms of time and money) required for testing such a model by far exceed the resources of this project. This implies that, once the overall didactic model has been specified, choices have to be made with respect to which aspect(s) should be given highest priority for further study.

This project will be specifically focussed on training simulators. The term "training simulator" covers a wide variety of different systems. Part of this variety is due to the fact that training simulators have been developed for different types of tasks. However, part of this variety is also due to the fact that simulators are based on different (generations of) technologies. In view of the fact that technology advances rapidly, this raises the issue what should be taken as the basis for thinking about what simulator-based training has to offer, i.e., should one take current simulators as a starting point or state-of-the-art simulator technology or (near-)future developments in simulator technology? A possible way out of this dilemma is to primarily focus on what would be ideal from a training and instruction point of view and to consider implementational possibilities and limitations only after this has been sorted out.

The core and ultimate goal of any training program is to effectuate learning by means of the execution of training activities. Apart from the nature of the training activity, the outcome of training strongly depends on the quality of the tutoring process. Compared to briefing and debriefing activities, tutoring is the most dynamic and time-critical aspect of instruction and probably also most characteristic of high-performance tasks. Also, the training process and the associated tutoring process impose the highest work load on trainees and the instructor, respectively. Tutoring is largely an intuitive process that is still poorly understood. For these reasons, the empirical work of this project will focus on this particular aspect.

3 RESEARCH ON TUTORING

Most of the research on tutoring has been conducted in the context of the development of Intelligent Tutoring Systems (ITSs). The purpose of these developments is to design computer

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[2] For instance, the effect of particular briefing activities is determined by the nature of the training activity which, in turn, is determined by the overall structure of the training program of which it is a part.

programs that teach in a more intelligent way. Researchers have tried to achieve this by applying tutoring concepts derived from the research literature and by applying techniques from the field of Artificial Intelligence (AI). The idea is to provide individualized and flexible tutoring in a way similar to human tutors. The main goal of ITS research is to implement, test and evaluate tutoring principles and ways to implement them.

ITSs are supposed to be more flexible than traditional Computer-Based Training (CBT) programs because they adapt training and instruction to the particular student. To realize this adaptability, designers have mostly followed a modular design approach, segregating the different kinds of knowledge that are supposed to be involved as far as possible. It is generally assumed that an ITS should include four kinds of knowledge (e.g., Wenger, 1987):

1 knowledge about what is being taught is contained in the *domain model,*
2 knowledge about the level, the strengths and the weaknesses of the particular student working with the system at a particular moment is contained in the *student model,*
3 knowledge about instructional strategies and tactics is contained in the *pedagogical model,*
4 knowledge about the way to present information to and get information from the student is contained in the *interface model.*

To be truly intelligent, all four components should be fully developed and integrated. Most ITS-studies are focused on a specific research issue, i.e., most researchers have concentrated on one of the models and designed the other models in a very rudimentary way or even not at all. Therefore, many famous ITS systems have never been fully developed or used in practice and only a few have been evaluated with students.

Another characteristic of research on ITSs is that it has been conducted predominantly in the context of relatively homogeneous and well-structured tasks (e.g., problem solving tasks), i.e., tasks that do not possess the dynamic, time critical, and time-sharing aspects that characterize high performance tasks. Given the complexity and dynamics of high-performance tasks, it is questionable whether current analytical approaches are also appropriate for these type of tasks. It is very likely that such approaches are so labourious that this factor alone limits or precludes their application (cf. Gonzalez & Ingraham, 1994, for a similar point).

Most ITS-developments are based on assumptions and concepts about tutoring derived from the literature instead of on an analysis of the way human tutors work. There are indications in the literature that the tutoring provided by human tutors differs from tutoring provided by ITSs (Merrill et al., 1992). However, the implications of these differences remain unclear. Is the goal to develop an optimal tutor or a tutor that accurately mimics the behaviour of human tutors? If the latter is the case one should try to minimize these differences. There are some difficulties here: one is that human tutors differ from each other, another is that human tutors commit errors. If the goal is to develop an optimal tutor one has to specify criteria. However, it is not possible to define absolute criteria. One can only conclude that one tutor produces better results than another. In short, this issue is an empirical one.

Despite the aforementioned shortcomings and limitations of ITS-studies, they may provide a useful starting point and source of inspiration for research on simulator-based tutoring.

3.1 Tutoring model

The scope of ITSs is often difficult to assess, i.e., it is not always clear whether an ITS is designed to test a specific tutoring concept or theory, an implementation technique or both. Also, it is not always clear what exactly is subsumed under the label "tutoring". Does it comprise sequencing and remediation decisions or does it only cover error correction and feedback? For practical reasons, a definition of tutoring should not be too broad. Following a rather narrow definition of tutoring, simulator-based tutoring proceeds in interaction with a training process. Conversely, briefing and debriefing activities, i.e., instructional activities executed prior to and after training scenarios, are frequently subsumed under tutoring. Among other things, briefing activities comprise activities intended to inform trainees about the training task that is to be performed. Debriefing activities include evaluations of trainee performance based on a review of performance during the training session. Although these activities are closely linked to tutoring activities and trade-off relations exist (e.g., trainee errors that are resolved during a training session do not have to be debriefed), it seems better to keep them separate.

A training process consists of the interaction between a trainee and a training scenario[3]. The tutoring process, whether automated or controlled by a human instructor, can be described in terms of a sequence of interventions into the training process by the instruction system (human and/or computer). Different categories of interventions can be distinguished, the most important being guidance, feedback, reinforcement, and diagnosis. Each of these categories may be subdivided into a number of more specific intervention categories, for instance, interventions associated with explaining, cueing and prompting can all be subsumed under guidance.

An intervention can be described in terms of condition-action rules. For instance:

IF ERROR THEN CORRECT

Different types of conditions can be distinguished, e.g., event based,

IF EVENTX THEN ACTIONA

time based[4], e.g.

IF ELAPSED TIME = 10 MINUTES THEN ACTIONB

---

[3] The scope of a training process will depend on simulator configuration. For simplicity's sake a one-to-one tutoring process is assumed.

[4] Time-based conditions can be specified in terms of absolute (scenario-)time or in terms of time relative to the occurrence of particular occurrences of events.

or based on multiple or composite conditions, for instance,

IF EVENTX AND EVENTY **THEN** ACTIONC

IF NOT(EVENTX) AND (TIME > 10.00) **THEN** ACTIOND

Similarly, different types of actions can be distinguished. An important distinction is between form (mode of presentation, lay out) and the content of an action.

Interventions can be viewed as "tutoring primitives". Conditions can be modulated by intervention rules. Such rules can be based on training history and/or intervention history. An example of the former (training history) is:

IF (N_OF_ERRORS < 10) AND (TIME_ELAPSED > 20 MINUTES) **THEN** DISABLE_INTERVENTION8

An example of the latter (intervention history) is:

IF N_OF_INTERVENTION8 > 2 **THEN** ENABLE_INTERVENTION10

Of course, intervention rules can be defined on both types of information. Rules provide the ability to adapt the tutoring process to trainee performance. Rules may be used to change conditions, change actions, or both, or to change the composition of the set of interventions, e.g., by disabling or by enabling particular interventions (cf. the two preceding examples). Apart from intervention rules, priority rules will generally be required in cases where the condition(s) of more than one intervention is being met.

The purpose of the research project proposed is to develop a tutoring model for high-performance tasks. Such a model may comprise a library of pre-defined intervention formats and an associated rule-base. By explicitly organizing/linking the selection of intervention formats and rules with task characteristics, application-specific tutoring models can be derived. By extending and/or (re-)organizing the library and rule-base, the model can be made more or less comprehensive.

In principle such a tutoring model can be described in terms of *pseudocode* i.e., a high level programming language (e.g., Masthoff, 1997). Such a pseudocode provides a more compact notation. In addition, using pseudocode facilitates checking the consistency of the model. Another advantage is that it can be translated more easily into software.

3.2 Model development

The development of the tutoring model as it was outlined in the previous section requires several steps. The following approach is proposed:

1 *Survey of instructional guidelines.* It could also be useful to investigate several different domains to be able to highlight common elements of instruction. Questions that should be answered involve:
- Which tutoring techniques have been identified/studied?
- Which tutoring techniques have been proven to be effective?
- To what extent have tutoring techniques been found to be specific for a particular task (domain) or medium?

A literature search is probably the best initial approach to these questions. The results may be used to set up a provisional tutoring model. This model can be used to generate questions for the next step.

2 *Instructor task analysis.* Instructor task analysis focuses on tutoring aspects, instructor qualifications, instructor courses. Relevant questions at this stage are:
- Which tutoring techniques do instructors use and why?
- To what extent do instructors differ in their use of tutoring techniques?
- How do instructors adapt their way of tutoring to particular trainees?
- To what extent are tutoring techniques specific for a particular task (domain)?
- To what extent are tutoring techniques specific for a particular training medium, in particular, to what extent does tutoring on the real system differ from instruction on a simulator?

Several research techniques could be of use in answering these questions:
- Structured interviews of instructors
- Systematic (video-)observation techniques (event sampling and time sampling techniques) of training sessions.
- Systematic expert review of (recorded) training scenarios.
- Analysis of simulator recordings/play backs.
- Observation studies of system. Analysis/review of video protocols/instrument recordings.

3 On the basis of the results of steps 1 and 2 the tutoring model can be elaborated and specified in a more formal way. At this step consistency checks can also be applied.

4 The following step is to test this model. One way to test the model is by checking whether different designers are able to end up with a similar tutoring model given a particular domain. A way to test the validity of the model is to check whether it can be used to describe the tutoring behaviour of instructors. At this step different domains may be used. It is expected that following this approach, a revised/more elaborate tutoring model can be specified.

5 The final step of the model development process consists of the experimental validation of the model by means of empirical studies. Which research techniques have been used to assess the effectiveness of tutoring?

The validation of the tutoring model pre-supposes the context of a training program. For the domain selected, a training program must be available in order to be able to measure the effects of tutoring.
A general problem with validation studies is that it may be difficult to distinguish between direct performance effects and learning effects. For instance, interventions may lead to a disruption of performance and, hence, to initial performance decrements. Also, the learning effects of different interventions may be superimposed and difficult or impossible to disentangle.

With respect to these steps, the choice of a training domain is important. This will be the main topic in the following chapter.

4 CHOICE OF TRAINING DOMAIN

According to the definition of high-performance tasks (Chapter 1), a large number of vehicle control tasks (ranging from riding a bicycle to flying an aircraft) could be classified under this header. Whether or not a task should be considered a high-performance task depends on a number of factors such as the time frame of the task and the number of skills required at the same time during task performance. The task load may differ within (sub)tasks (during the course of task-performance) as well as between (sub)tasks. Both points have consequences for the representativeness of such a task (i.e., does it conform to the definition of a high-performance task).
In the next paragraphs representativeness will be discussed for a diverse selection of vehicle control tasks on the basis of a classification in water-, land-, and air-vehicles.

Water vehicles include sailboats, yachts, oil tankers, and submarines

The control of ships is usually not considered as very representative of high-performance tasks. The relative inertia of a ship (especially of larger ships) causes the operators steering inputs to be effective only after some time (Bles, Korteling, Marcus, Riemersma & Theeuwes, 1991). Therefore, control is far more involved with planning than with executing a motor program. Although it may be expected that the requirement to perform multiple tasks simultaneously at times imposes a rather heavy cognitive load on the operator, there are no abrupt changes in the dynamics of the system or its environment.

Land vehicles include bicycles, mopeds, motorbikes, cars, trucks, and tanks

Due to the extremely interactive nature of present day traffic the environment of the driver can be considered very dynamic. Land vehicles can reach considerable speeds (except for most bicycles maybe) that impose an incremental burden on the human information processing capacity. The driver of a land vehicle has to respond to (unexpected) situations while

attending to his lateral and longitudinal position on the road, and to other vehicles. Trainees have to meet certain criteria with regard to their perceptual capabilities (esp. vision and hearing) and health in general to gain admission to a training program for a land vehicle. Learning to drive a land vehicle, requires quite some training: In The Netherlands, driver's education takes an average of 20-40 training hours before students are allowed to take their driving test. Still, a considerable percentage of students (63%) fails on their first attempt to pass. Furthermore, one of the reasons young drivers are prone to become involved in accidents is their limited driving experience in terms of distance travelled. Therefore, controlling most land vehicles can be considered as representative of high-performance tasks.

Aircraft include commercial (passenger) aircraft, fighter jets, glider planes, and helicopters

The speed at which an aircraft travels, by far exceeds that of land vehicles. Still, the environment is somewhat less demanding because the traffic density is relatively low. Vehicle dynamics are different for each type of vehicle but generally more complex than for car driving because the height of the aircraft has to be controlled as well. Glider planes, for example, are relatively stable whereas helicopters are inherently unstable, hence much more difficult to control. The flying of a fixed wing aircraft is not very demanding normally. Most difficulties are associated with take-off and landing. In this phase the need for high-performance aspects of the task are most obvious. Nonetheless, the requirements for planning and communication during flight are considerable, especially when flying in the neighbourhood of airfields (where interactions with other aircraft are likely to be frequent). Students are subjected to physical and psychological tests prior to assignment to the initial flight training program. Especially in the military, selection is very strict because the pilots are trained to operate under extreme conditions (i.e., low-level flight, high G-forces, dog-fight) where the slightest control error could be fatal.

Other factors

It could be stated that the best example of a high-performance task is the task that imposes the highest load on the operator. However, this does not imply automatically that this particular task is best suited for researching. Apart from its ***representativeness,*** other factors of the domain, relating to the ***accessibility*** of the domain, will have to be considered such as the *availability of scientific knowledge,* this concerns not only the number of relevant publications but also the possibilities to obtain them; *the familiarity with the domain,* this refers to the additional effort the contributors have to invest to collect fundamental knowledge about the domain (or knowledge of 'networks' of people that possess valuable domain specific information); *the research facilities,* what possibilities do exist to investigate the domain, how easy is it to find subjects to participate in an experiment; and the *practical relevance of the domain.*

Since water-vehicles do not seem to be very good representatives of high-performance tasks in the first place, the remainder of this text will focus on land-vehicles and aircraft. From

these domains two options have been considered in more detail, viz. car driving and helicopter flight.

4.1 Car driving

Car driving is one of the promising areas for research on a didactic model. It involves perceptual skills, motor skills, cognitive skills, and time sharing skills. With the increasing density of both traffic and information, the dynamics of the environment impose a heavy load on the driver. Inexperienced drivers are responsible for a comparatively large part of the total number of traffic accidents. This is partly caused by the fact that a lot of emergency situations are not encountered in the driving lessons. At this point a simulator would be perfectly suited to provide additional assistance to the students.

The instructional process is taken care of by specialized instructors in specialized schools. Training consists of theory as well as practice. Ideally these two parts would be integrated to a large extent. The use of simulation techniques would facilitate a level of integration that cannot easily be realized with the present instructional methods.

Since there is considerable competition between driving schools, schools are looking for ways to improve their instructional efficiency and effectiveness to attract new students (some schools use video recordings of the lessons so they can provide extra feedback afterwards, others offer special intensive courses that take only as long as two weeks). As the procurement costs of simulators are falling, currently, interest in the applicability of simulators for (part of the) driver training is rising. Simulators have a certain appeal to people that probably relates to the popularity of video games. Therefore, the use of a simulator might be an extra motivation for the students. A training simulator mainly is expected to improve the didactic aspects of the training, and assist the instructors judgement.

Available scientific knowledge

The application of simulators to driver training requires development of a didactic model that specifies (and ideally predicts) the relation between the instructional process and its outcomes. Therefore, it is essential to have solid knowledge of the desired outcomes. This could be based partially on an comprehensive task analysis of car driving (e.g., McKnight & Adams, 1970; Van Winsum, 1996). A working model that applies to a domain with students so diverse as in car driving might easily be adapted for implementation in other domains. On the other hand, its non-uniformity might complicate the interpretation of experimental results.

Recently, a number of studies have investigated the potential of alternative instructional methods (i.e., simulator training) in driving lessons (e.g., Wierda 1993, 1994). The results of these studies hold promise for simulator training.

Familiarity and relevance

Most people have their drivers licence, the contributors involved in this project included. Although this does not (automatically) make them experts on driver training it certainly adds to their familiarity with the domain. Furthermore, the results of this study will be relevant to a large number of people.

Research facilities

Throughout the country, driving schools provide instruction. The total number of trainees is large, most of them are highly motivated to pass the driving test. Hence, it may be expected that it will be easy to recruit subjects for experimental research. Finding instructors willing to cooperate may be slightly more difficult because of their busy schedules. It might, however, be possible to find a way to cooperate with the school where instructors themselves receive their education.
Within TNO-HFRI, the department of Traffic Behaviour has considerable knowledge with respect to car driving. There are contacts with the Dutch Army (which has its own driving schools), the VVN (the Netherlands Organization for Traffic Safety), and the Traffic Research Centre (VSC) of the University of Groningen. TNO-HFRI has its own driving simulator recently equipped with a moving base platform which is also suited for experimental research. Furthermore, in the Netherlands, other driving simulators do exist but these are mainly used on a commercial basis. There are at least two other countries in Europe that use a driving simulator for research: Great-Britain and Sweden.
In the USA interest in driving simulators is also growing. At the University of Massachusetts for example, researchers are investigating the training possibilities of their driving simulator (MIDAS; Massachusetts Interactive Driving and Acoustic Simulator). A visit to a simulator facility abroad might be an interesting option in a later stage of the research project.

4.2 Helicopter flight

The inherent instability of the helicopter makes this vehicle particularly unforgiving to errors. While flying a helicopter, there is a constant need for correcting its instability (comparable to a stick balancing task). At the same time, the aviator has to watch the environment, scan a number of displays, and communicate with others. In other words, helicopter flying seems to be the ultimate high-performance task.
Learning to fly a modern helicopter would be impossible without the use of simulators, not just from a didactic point of view but also with regard to issues such as safety and costs. An unsuspicious mind could suspect that the high need for simulation would have led to the development of a didactic model for helicopter flying. Surprisingly, this is not the case. Most training programs have been developed on the basis of the common sense notions of instructors who are more often expert pilots than experts in the field of instruction. There is very little empirical research comparing the performance of students as a function of different

training programs. Therefore, the validation of training simulators (in general) is missing. One limiting factor is that it is not possible to judge "baseline" performance without simulator training. At best the results can be of quasi-transfer-of-training studies comparing different simulator configurations. Mentioning the lack of validation studies is not to suggest that helicopter training is not *effective.* In fact, practice, and ample anecdotal evidence suggests it is. What remains unknown, however, is the *efficiency* of the training. That is, the design of training from a scientifically founded point of view could lead to reduction in training time, effort, or costs.

Available scientific knowledge

The literature with regard to helicopter flying is concerned mainly with helicopter handling qualities. Training aspects seem to be underrepresented. Even in the literature written for the purpose of training itself, e.g., the Crew manual for the Chinook transport helicopter, strikingly little information on to be preferred training strategies is presented. Only objectives are stated.

Familiarity

Most people know little of helicopter flight. The same applies to the contributors to this project. None of them can actually fly a helicopter even though they may have gained relevant knowledge from the literature. This makes it difficult to estimate their familiarity with the domain. With regard to the practice of helicopter training they can be said to be inexperienced.

Research facilities

Currently, at TNO-HFRI, effort is put in the development of a helicopter simulator facility for research purposes. However, it is not expected to be operational within the next year. There are at least two good helicopter simulators in Europe on which virtually all aspects of helicopter flight can be trained. Training in the Netherlands can be done in Den Helder with the Lynx simulator facility. Otherwise training takes place on the operational system or in simulators abroad.

The number of trainee pilots and instructors is fairly small compared to numbers for car driving. A large part of pilots is employed by the RNLAF. Considerable parts of their education have to take place in the USA. This complicates research on trainees. Although good contacts with the air force do exist, experimental subjects have to be requested a considerable period in advance.

4.3 Conclusion

It seems that helicopter flight is the best representative of a high-performance task. There are, however, questions concerning its accessibility: The number of trainees is rather limited. The length of training is considerable and partly abroad which might limit the possibilities for experimental research. Car driving seems to be better suited for research because it is expected that trainees can be easily recruited. At any time students of any level will be available to experiment with. A potential drawback might be the fear of instructors to lose their jobs as a result of complete automation of instruction. This is not our goal. We think driving instructors should get acquainted with a new tool in education that will assist them, and make things easier for them, but not replace them.

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GLOSSARY

Briefing	Instruction support prior to the execution of training activities.
Debriefing	Instruction support after the execution of training activities.
Didactic model	Model that specifies the relation between training and instruction factors and learning.
Fidelity (functional)	The similarity between the trainee's behaviour on the simulated task (perceptual, motor, and cognitive processes) and on the operational task under similar conditions.
High performance task	Complex, time critical task where the operator is in the primary control loop of the system.
Instruction factors	Factors related to the support provided before, during, and after the execution of training activities.
IOS	Instructor/Operator System.
ITS	Intelligent Tutoring System.
Learning	A relatively permanent change in behaviour due to training.
Simulator	Research or training device that mimics (a part of) a real task environment. It is possible to present specific events in the form of a scenario. Behaviour in the simulator can be recorded and analysed.
Training factors	Factors that are related to the sequencing, frequency, spacing, duration and content of training activities.
Tutoring	Instruction support during the execution of training activities.
Validity	The extent to which skills acquired in a simulator transfer to the operational equipment.

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15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTES))

With advances in simulation technology, simulators are increasingly used as a medium for training and instruction. This report contains a description of a proposal for a research project aimed at the development of a generic didactic model for training simulators; notably as it applies to learning requisite skills for performing high-performance tasks.
A didactic model specifies the relation between learning, and training and instruction factors. The development of such a model is motivated by the need to control training and instruction factors in research on simulator fidelity, the need to assess the benefit of training simulators, e.g., relative to other training media, and the need for developing more efficient instructional systems to support simulator-based training and instruction. For several reasons, it is proposed to focus the empirical work on tutoring aspects associated with car driving skills.

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